No-till spring cereal cropping systems reduce wind erosion susceptibility in the wheat/fallow region of the Pacific Northwest

M.E. Thorne, F.L. Young, W.L. Pan, R. Bafus, and J.R. Alldredge.

ABSTRACT: The dust-mulch fallow phase of winter wheat (*Triticum aestivum* L.) production in low-rainfall areas of the Columbia Plateau leaves the soil surface loose-structured and exposed to erosion during high winds common to the region, and is a major source of airborne particulate matter. The objective of this research is to evaluate no-till spring cropping as an alternative to traditional winter wheat/dust-mulch fallow in reducing wind erosion susceptibility. Surface residue cover, random roughness, and crop canopy coverage were measured during a 3-year transition period from winter wheat/fallow to no-till spring cereals. These measurements were applied to soil loss ratio models as indices of wind erosion susceptibility. No-till spring cereal rotations reduced erosion susceptibility compared with winter wheat/fallow by maintaining soil cover during spring and fall when erosion is high. Crop canopy cover reduced erosion susceptibility after fall seeding in winter wheat/fallow and after no-till spring seeding. This research indicates that no-till spring cropping would significantly reduce wind erosion in winter wheat/fallow areas.

Keywords: Annual cropping, crop residue cover, random roughness, soil loss ratio

Wind-borne soil erosion from cropland in the Columbia Basin and Plateau of eastern Washington and Oregon is a major concern for air quality in the region (Saxton 1995). Airborne particulate matter (PM) is associated with health problems and increased mortality rates for people with heart and respiratory diseases (DíAmato, 1999; Zanobetti et al., 2000; Hruba et al., 2001; Scwartz, 2001) and is a source of carcinogens (Timblin et al., 1998). In addition, several fatal traffic accidents have occurred in the Inland Northwest due to poor visibility from dust blowing across roadways (Hunsberger et al., 1999; Sorensen, 2000).

In 1970, the U.S. government passed the Clean Air Act, later amended in 1990, requiring the U.S. Environmental Protection Agency (USEPA) to establish National Ambient Air Quality Standards (NAAQS) pertaining to human-source-pollutants (USEPA, 1990). Dust emission levels in the Northwest from both farm and nonfarm sources have exceeded NAAQS on various occasions. As an example, in 1992 airborne particulate matter less than 10 μm in diameter (PM10) reached peak levels between 600 and 800 $\mu g\ m^{-3}$ in two eastern Washington cities during September dust storm events (Saxton, 1995). These maximums exceeded the average acceptable daily limit of 150 $\mu g\ m^{-3}$ (USEPA, 1990) and occurred on days of visible wind erosion (Saxton, 1995).

Dust emissions are highest in the low rainfall winter wheat/fallow region of the Columbia Plateau where winter wheat is grown in alternate years following a year of dust-mulch fallow (Saxton et al., 2000).

Mark E. Thorne is an associate in research and **Frank L. Young** is a research agronomist with the U.S. Department of Agriculture's Agricultural Research Service. **William L. Pan** is a soil scientist and **J. Richard Alldredge** is an agricultural statistician at Washington State University in Pullman, Washington. **Rhonda Bafus** is a research assistant at the Central Oregon Agricultural Research Center in Madras, Oregon.

Regional soils are characterized by low organic matter content, poorly aggregated silt loam texture, and easily suspended particles. During the fallow year, the dust-mulch layer is prepared by tilling the soil to create a loose, unstructured surface layer of small-grained soil particles and chopped residue that acts as a barrier to soil moisture evaporation (Papendick et al., 1973; Schillinger and Papendick, 1997). Numerous tillage operations are performed throughout the summer and fall to control weeds and maintain the dust-mulch layer. During this time, strong winds promote fugitive dust emissions from dry exposed soil surfaces (Saxton, 1995; Papendick, 1998).

Research in the Columbia Plateau Region using controlled wind tunnel experiments identifies soil residue cover (SRC) and surface random roughness (RR) as key factors in reducing particulate matter emissions (Horning et al., 1998). This research relates erosion potential to the combined effects of soil residue cover and random roughness using a soil loss ratio (SLR) model. This soil loss ratio is directly applicable to evaluating soil conservation efforts on the Columbia Plateau because it is based on actual winter wheat/fallow field experiments. Previous wind tunnel research using nonerodible artificial soil clods (Fryrear, 1984) and wood dowels (Fryrear, 1985) supports the general finding of Horning et al. (1998) that soil surface structure is important in reducing soil loss due to wind erosion. Soil residue cover and nonerodible clods reduce erosion by forming a protective barrier over the soil surface that reduces both wind velocity and exposed erodible surface (Siddoway et al., 1965; Fryrear, 1984).

No-till spring cropping is proposed as an alternative to winter wheat/fallow on the Columbia Plateau. In the Great Plains Region, no-till spring cropping is being examined as a replacement for winter wheat/fallow to reduce soil erosion (Merrill et al., 1999). In comparison to winter wheat/fallow, no-till increases soil residue cover and eliminates the dust-mulch fallow period, thus increasing the cropping system's resistance to wind erosion (Merrill et al., 1999). However, since rainfall patterns differ dramatically between the two regions, transition to no-till spring cropping may produce completely different outcomes, or may not even be feasible on the Columbia Plateau. Currently, only a few growers within the low-rainfall Columbia Plateau Region practice no-till farming, but this may increase if appropriate production practices are researched and incorporated and outcomes become more predictable. Therefore, the primary objective of this research is to evaluate no-till spring cropping in reducing wind erosion susceptibility using appropriate soil loss ratio models. Information from this research is critical in defining the potential of no-till cropping within the traditional winter wheat/fallow production zone of the Columbia Plateau.

Methods and Materials

In late summer of 1995, a large-scale cropping system study was established on a dryland (nonirrigated) cooperator's farm located in central Adams County, Washington (T 17N, R 35E). In contrast to traditional winter wheat/fallow farms of the region, the cooperator has historically used innovative farming practices integrating various crops under conservation tillage or no-till methods to maintain residue on the soil surface. Primary crops have been winter wheat, spring wheat (*Triticum aestivum* L.), spring barley (*Hordeum vulgare* L.), and winter and spring canola (*Brassica* spp.).

Long-term plots were established in two adjacent, relatively level fields separated by a north-south county road. At the start of the study, the field on the east side (ES) of the road was in standing stubble produced from the 1995 winter wheat crop and the field on the west side (WS) of the road was in fallow to be planted to winter wheat. Both east side and west side locations contained sixteen plots, measuring 9 m by 152 m (30 × 500 ft), arranged side by side and separated by a 3-m (9.8 ft) alley. The plots were at least 30 m (98 ft) from any field edge to minimize border effect. Soil in both fields was classified as a Ritzville silt loam (coarse-silty, mixed, mesic, Calcidic Haploxeroll) with a texture of 30% sand, 62% silt, and 8% clay. Organic matter averaged 2.0 and 1.9% in east side and west side plots, respectively, and overall slope was less than 2%.

The experimental design was a randomized complete block with measurements repeated each year. Treatments consisted of a combination of crop rotation and field location, each replicated four times (Table 1). Rotations evaluated were (i) winter wheat/fallow, (ii) no-till spring wheat/chemical fallow (SW/CF), (iii) no-till continuous spring wheat (CSW), and (iv) no-till spring wheat/spring barley (SW/SB). All four rotations were contained in both east side and west side. Because of initial moisture and rotation differences (east side stubble and west side fallow), the experiment included eight different treatments, at least for the early transition period (Table 1). In addition, all plot operations were conducted with farm-

Table 1. Description of rotations and phases in relation to field location in a dryland cropping system project on the Columbia Plateau of eastern Washington.

Location*	Rotation		Rotation phases 1995-96	1996-97	1997-98
WS	winter wheat/dust-mulch fallow	(WW/F)	WW	F	WW
WS	no-till spring wheat/chemical fallow	(SW/CF)	SW	CF	SW
WS	no-till continuous spring wheat	(CSW)	SW	SW	SW
WS	no-till spring wheat/spring barley	(SW/SB)	SW	SB	SW
ES	winter wheat/dust-mulch fallow	(WW/F)	F	WW	F
ES	no-till spring wheat/chemical fallow	(SW/CF)	CF	SW	CF
ES	no-till continuous spring wheat	(CSW)	SW	SW	SW
ES	no-till spring wheat/spring barley	(SW/SB)	SB	SW	SB

* **West side (WS) plots were initially in dust-mulch fallow and east side (ES) plots in winter wheat stubble during fall 1995.**

sized equipment. Annual precipitation, recorded at a nearby station from 1995 through 1998 averaged 382 mm (15.1 in). Annual precipitation averaged over the past 20 years was 260 mm (10.2 in).

Winter wheat/dust-mulch fallow. The west side winter wheat/fallow plots were seeded September 19, 1995, to Lewjain soft-white winter wheat using a John Deere HZ 616 deep-furrow drill with 40 cm (15.8 in) row spacing. Following crop harvest July 29, 1996, stubble remained standing until May 12, 1997, when it was mowed to a height of 15 cm (5.9 in) to reduce straw length. Plots were initially tilled May 14, 1997, with a disk harrow (disk) and attached rolling basket harrow at a depth of 8 cm (3.2 in) to prevent formation of large soil clods during undercutting. On June 23, 1997, the plots were undercut and fertilized with a Haybuster® noninversion tillage implement using 0.8-m (2.6 ft) V-shaped sweeps at a depth of 13 cm (5.1 in). Secondary tillage was performed with a set of three 3 m (9.8 ft) Calkins® rodweeders with 1.9 cm (0.75 in) square rods. Plots were rodweeded July 16, 1997, to a depth of 5 cm (2 in) for weed control and seedbed preparation, then seeded September 5, 1997, to Lewjain winter wheat. The plots were harvested July 23, 1998.

Following the 1995 wheat harvest, east side winter wheat/fallow plots were lightly disked (<3 cm) (1.2 in) to incorporate downy brome (*Bromus tectorum* L.) seed into the soil. The operation retained the integrity of the deep furrows and wheat crown roots and left the majority of the residue on the surface. The plots were undercut and fertilized May 6, 1996, and rodweeded June 6 and August 1, 1996. On September 9, 1996, Lewjain winter wheat was seeded; however, rainfall shortly after planting crusted the soil surface and prevented the crop from emerging. The plots were rodweeded September 30, 1996, to loosen the crusted soil and kill a flush of weeds before reseeding to Lewjain winter wheat using a John Deere 9400 hoe-opener drill with 18 cm (7 in) row spacing. The winter wheat crop was harvested August 13, 1997, and the stubble was lightly disked (5 cm) (2 in) September 4, 1997, to incorporate weed seed. The plots were undercut and fertilized April 29, 1998, and rodweeded June 2, June 29, and July 27, 1998.

No-till spring cereal systems. All spring cereal crops were seeded with a John Deere 9400 hoe-opener drill with 18 cm (7 in) row spacing. The drill was equipped with 6 cm (2.4 in) single-point hoe openers capable of penetrating nontilled soil. Some soil disturbance occurred during each seeding operation from the hoe openers digging furrows approximately 6 cm (2.4 in) wide. The drill was also capable of applying both dry and liquid fertilizers making it applicable as a one-pass, no-till drill.

The west side spring wheat/chemical fallow plots (dust-mulch fallow in 1995) were planted March 19, 1996, to Alpowa soft-white spring wheat. Plots were harvested August 5, 1996, and stubble remained standing in the field until March 14, 1998, when Alpowa spring wheat was seeded. Following the 1995 harvest, east side spring wheat/chemical fallow plots were left in standing winter wheat stubble. On January 13, 1996, Russian thistle (*Salsola iberica* Sennen and Pau) skeletons left from the 1995 winter wheat crop were mowed with a 3-point 2 m (0.79 in) rotary mower to allow herbicides to reach weed seedlings, and to reduce interference with the next seeding operation. The plots were seeded March 24, 1997, to Alpowa spring wheat and harvested August 7, 1997. During the fallow periods, weeds were chemically controlled in all plots with various herbicides (Thorne and Young, 1998; Launchbaugh et al., 2000).

The continuous spring wheat and spring wheat/spring barley plots were seeded no-till in March of each year using a John Deere 9400 drill with the initial 1996 west side seeding into dust-mulch fallow. Crop cultivars were Butte 86 hard-red spring wheat and Baronesse 2-row spring barley. Standing stubble and flat crop residue remained on the soil surface between harvest and planting. In October of each year, a portion of the required nitrogen for hard red spring wheat was applied as liquid fertilizer to plots to be seeded the following spring with an applicator equipped with coil shanks spaced 30 cm (11.8 in) apart. All plots were harvested between August 3 and August 5 of each year.

Measurements for surface residue, crop canopy, and random roughness. Measurements characterizing surface vegetative residue and soil roughness were recorded following field operations beginning in fall 1995 and ending following harvest 1998; however, not all treatments were sampled at each time due to differences in rotations. Flat (not standing) soil residue cover and percent canopy cover (CC) were estimated with a string-and-bead point-intersect method using a 15.2 m (50 ft) nylon cord with 100 12 by 5 mm (0.47 × 0.2 in) plastic beads spaced 15 cm (5.9 in) apart stretched across the surface of each plot at a 45-degree angle (Sloneker and Moldenhauer, 1977). Percent soil residue cover was calculated as the number of beads intersecting nonliving plant material directly below a pre-specified point on one side of each bead, divided by the total number of beads. Percent canopy cover estimated the percent of ground covered by crop canopy and was determined using the string-and-bead method described for soil residue cover. The number of beads directly below living canopy vegetation was determined by visualizing a perpendicular line between the vegetation and the bead. Six measurements of soil residue cover and canopy cover were made in each plot.

Random roughness is an index of cloddiness and random microtopography and measures the standard deviation of soil surface elevations, not including ridges created by tillage or planting equipment (Allmaras et al., 1966). In our research, random roughness was evaluated visually by comparing the soil surface to photographs of soil surfaces with random roughness of 0.6, 1.0, 1.7, 1.9, 2.2, 2.6, 4.1, and 4.3 cm (0.24, 0.39, 0.67, 0.75, 0.87, 1.02, 1.6, and 1.7 in) standard deviations (SDV_{cm}) (SDV_{in}) (McCool et al., 1996). These photographs were calibrated with 10 profile meter readings of 145 pins on 12.5 mm (0.48 in) spacing. The 0.6 cm (0.24 in) photograph pictured a nearly flat surface with small clods not more than approximately 1 cm (0.39 in) diameter; the 4.3 cm (1.7 in) photograph characterized a rough surface with clod size up to approximately 15 cm (5.9 in) diameter. Six comparisons were made per plot at each sample time. This method was invaluable because of the number of plots and time constraints, and was the method used to determine random roughness for the Horning et al. (1998) soil loss ratio model.

Soil surface effects of random roughness and soil residue cover were used to calculate a soil loss ratio as an index of predicted wind erodibility of the soil surface (Horning et al., 1998). The soil loss ratio values range from 0 to 1 with 1 representing maximum erosion from a smooth, bare, unprotected soil. Both soil residue cover and random roughness are combined in the Horning et al. (1998) equation:

$$SLR = e^{-0.05\ SRC} \times e^{-0.52\ RR} \quad (1)$$

where:

SRC = percent cover of residue laying relatively flat on the soil surface,

RR = random roughness is random roughness measured as SDV_{cm}.

In this equation, soil loss ratio is more sensitive to soil residue cover than to random roughness (Figure 1).

A second soil loss ratio based on canopy cover (SLR_{cc}) was used to estimate the effect of the growing crop in reducing wind erosion potential. The following equation from the Revised Wind Erosion Equation (RWEQ) (Fryrear et al., 1998 [Equation 21])

$$SLR_{cc} = e^{-5.614}\ CC^{0.7366} \quad (2)$$

uses canopy cover expressed as the fraction of soil covered by the growing crop canopy. To estimate the combined effect of soil residue cover, random roughness, and canopy cover, Equations 1 and 2 were multiplied together to produce a combined soil loss ratio (SLR_{comb}) (Bilbro and Fryrear, 1994)

$$SLR_{comb} = SLR \times SLR_{cc} \quad (3)$$

Data were analyzed using Statistical Analysis Software mixed-model procedure (Littell et al., 1996) with rotation, sample date, and blocks as class variables. When a significant interaction ($P \leq 0.05$) existed between rotation and sample date, pairwise comparisons of least squares means were made for each combination of rotation and date with a protected LSD test using the pooled variance from the full model.

Results and Discussion

Winter wheat/dust-mulch fallow. Growers' standard tillage practices in the area surrounding the experimental site have traditionally been more aggressive than practices used in our winter wheat/fallow rotation. Standard dust-mulch fallow preparation has included a fall disking and chisel plowing, two cultivator operations in the spring, one skew-treader operation, and a minimum of two rodweedings between June and August (Hinman and Esser, 1999). Alternatively, some growers have replaced the cultivator and skew-treader operations with up to six passes with a rodweeder (personal observation, Thorne). In our research, a shallow disking and undercutting were the only primary tillage operations and are considered conservation tillage practices as they leave a high percentage of both flat and standing residue (Schillinger and Papendick, 1997; Papendick, 1998). Even with reduced tillage, soil residue cover in east side plots was 13% and soil loss ratio was 0.253 following primary tillage in 1996 (Table 2). In 1997, spring primary tillage decreased soil residue cover in west side plots from 92% to 46%.

In winter wheat/fallow plots, soil residue cover was highest following crop harvest and lowest prior to seeding, regardless of field location (Table 2). Winter wheat in west side plots produced greater amounts of biomass than in east side plots (5600 kg ha^{-1} compared to 5040 kg ha^{-1} respectively) (5000 lb ac^{-1}, 4500 lb ac^{-1}) (Thorne and Young, 1998; Launchbaugh et al., 2000) and yielded higher soil residue cover following wheat harvest. Consequently, west side plots had lower soil loss ratio values during the fallow year than east side plots. Random roughness was greatest during the dust-mulch fallow period due to clod formation during primary tillage and was influential in reducing soil loss ratio when soil residue cover was low (Table 2). However, random roughness decreased during the winter period from weathering and snowmelt that left the soil surface smooth and crusted. At that time the erosion potential was probably lower than soil loss ratio indicated since wet or crusted soil is typically less erodible in this region than dry, loose soil (Saxton et al., 2000).

Secondary tillage did not decrease soil residue cover during the 1996 and 1997 fallow years in east side and west side plots, respectively (Table 2). Prior to fall seeding each year, soil residue cover was greater than 40%, and the soil loss ratio was less than 0.1 indicating the soil was well protected from wind erosion. In earlier research from the same farm, Schillinger and Papendick (1997) also found no loss in soil residue cover following secondary tillage with a rodweeder. In our research, initial rodweeder operations

Figure 1

Soil loss ratio (SLR) in relation to soil residue cover (SCR) and random roughness (RR) as a function of the equation $SLR = e^{-0.05 \times SRC} \times e^{-0.52 \times (RR)}$. RR values are • = 0.0 cm, ■ = 0.6 cm, ◆ = 1.0 cm, □ = 1.7, ○ = 2.2 cm and represent standard deviations of surface elevations in relation to a flat surface.

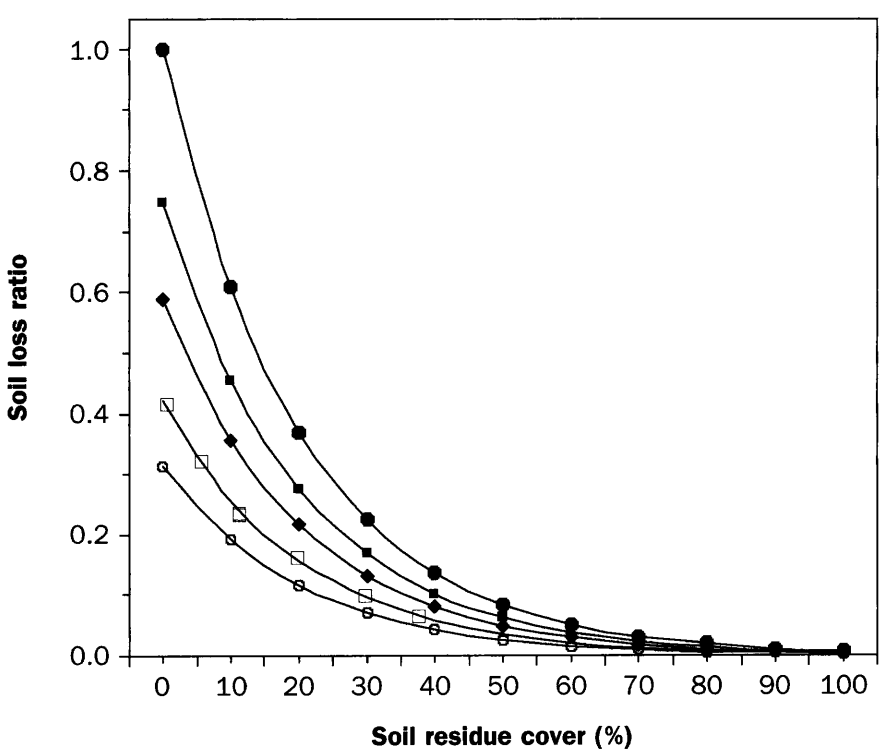

Table 2. Effect of winter wheat/dust-mulch fallow (WW/F) rotations on wind erosion susceptibility as indicated by a soil loss ratio (SLR) combining surface random roughness (RR) and flat soil residue cover (SRC).*

Sample date	Rotation phase	RR	SRC	SLR
		(SDV_{cm})	(%)	(index)†
West side location				
September 1995	dust-mulch fallow - pre-seeding	1.27c	17.0hi	0.226c
October 1995	post winter wheat seeding	1.28c	16.4hi	0.231c
March 1996	winter wheat crop (overwinter)	0.84ef	16.9hi	0.304a
March 1997	winter wheat stubble	0.71fg	91.7a	0.007g
May 1997	post primary tillage (disk harrow)	1.07d	44.3de	0.071ef
June 1997	post primary tillage (undercut)	1.02de	46.2d	0.065ef
July 1997	post secondary tillage (rodweed)	1.02de	57.3c	0.036fg
March 1998	winter wheat crop (overwinter)	0.83ef	20.9h	0.237c
August 1998	winter wheat stubble	0.86ef	94.1a	0.006g
East side location				
May 1996	post primary tillage (fall disk harrow and undercut)	1.42b	12.9i	0.253bc
July 1996	post secondary tillage (rodweed)	1.33c	37.2f	0.082e
August 1996	post secondary tillage (rodweed)	1.64a	40.3ef	0.059ef
March 1997	winter wheat crop (overwinter)	0.60g	29.3g	0.181d
August 1997	winter wheat stubble	—	77.0b	—
March 1998	post primary tillage (fall disk harrow)	1.62a	39.1ef	0.067ef
June 1998	post primary tillage (undercut)	—	—	—
June 1998	post secondary tillage (rodweed)	1.65a	21.4h	0.153d
August 1998	post secondary tillage (2x rodweed)	1.17cd	13.5i	0.284ab

* All means within each category followed by the same letter are not significantly different ($\alpha = 0.05$). Simple effects are compared using protected LSD tests due to an interaction ($P \leq 0.001$) between rotation and sample date.

† 0 = no erosion, 1 = maximum erosion potential.

increased soil residue cover in 1996 and 1997 and was potentially a result of the rod lifting buried residue back to the surface while rotating counter to the direction of travel under the soil surface.

In contrast, soil residue cover declined from 39.1% to 13.5% in east side plots during the 1998 fallow year (Table 2). After the third rodweeding, the soil loss ratio was 0.284 representing the highest erosion potential during any of the three fallow periods. The low fallow soil residue cover may have been due to less winter wheat biomass produced the previous year (Thorne and Young, 1998). However, disking following the 1997 east side harvest was deeper than the 1995 east side post-harvest disking and may have buried more residue and promoted more residue decomposition through the winter. In contrast, spring-disked winter wheat stubble had less time to decompose before the rodweeder pulled it back to the surface. Sloneker and Moldenhauer (1977) also found that soil residue cover was higher following spring disking if crop residues were left standing through the winter.

Under the Food Security Act of 1985, the U.S. Department of Agriculture-Natural Resources Conservation Service (USDA-NRCS) is required to set Alternative Conservation System requirements for highly erodible land. The Alternative Conservation System minimum residue cover for winter wheat/fallow for the farm supporting this research is 390 kg ha^{-1} (348 lb ac^{-1}) or approximately 20% soil residue cover. Consequently, the winter wheat/fallow system in this research would have been out of compliance with Food Security Act intent during the 1995 west side and 1998 east side fallow periods as soil residue cover was less than 20% (Table 2).

Continuous no-till spring crops. In continuous spring wheat and spring wheat/spring barley rotations, random roughness had little effect on soil loss ratio when crop residues were left undisturbed on the soil surface (Table 3). However, random roughness increased following the 1996 seeding from clods produced by the hoe-opener drill but decreased through the fall and winter from weathering and snowmelt. In 1997, random roughness did not increase during seeding due to less soil fracturing.

Average crop biomass produced during the 3-year research period was 4700 kg ha^{-1} (4196 lb ac^{-1}) and 3950 kg ha^{-1} (3527 lb ac^{-1}) for west side and east side continuous spring wheat respectively. For the 2-year no-till rotation, biomass ranged from 3500 to 4040 kg ha^{-1} (3125 to 3607 lb ac^{-1}) for spring wheat and 2920 to 4160 kg ha^{-1} (2607 to 3714 lb ac^{-1}) for spring barley depending on the year and field. Surface residue cover in west side continuous spring wheat and spring wheat/spring barley plots was low prior to the initial March 1996 spring seeding into dust-mulch fallow (Table 3); soil residue cover in east side plots was not measured prior to the initial seeding but winter wheat residue remained from the 1995 harvest. We would expect east side soil residue cover to be at least 50% following the 1995 harvest since soil residue cover was > 70% following the 1996, 1997, and 1998 winter wheat harvests. After the rotations were established, crop residue remained on the surface and resulted in low soil loss ratio values that were similar between years and rotations (Table 3). Each spring, no-till seeding decreased soil residue cover and increased soil loss ratio as the drill

Table 3. Effect of no-till rotations on wind erosion susceptibility as indicated by a soil loss ratio (SLR) combining surface random roughness (RR) and flat soil residue cover (SRC).*

Sample date	Rotation phase	RR		SRC		SLR	
		WS†	ES	WS	ES	WS	ES
		(SDV$_{cm}$)		(%)		(index)†	
No-till continuous spring wheat							
March 1996	Pre-plant (dust-mulch fallow)	1.87a	—	19.5kl	—	0.153cde	—
March 1997	Pre-plant (spring wheat stubble)	1.38de	0.91hijk	75.5cde	70.1ef	0.012g	0.020g
May 1997	Post-plant (first no-till seeding)	1.83ab	1.67abc	23.7ijk	32.2h	0.124ef	0.091f
March 1998	Pre-plant (spring wheat stubble)	1.02ghi	1.02ghi	72.8de	76.5cd	0.016g	0.013g
June 1998	Post-plant (second no-till seeding)	1.02ghi	1.02ghi	27.8hi	26.4ij	0.151cde	0.165bcd
August 1998	Post-harvest (spring wheat stubble)	1.02 ghi	1.02 ghi	94.0 a	94.8 a	0.005 g	0.005 g
No-till spring wheat/spring barley							
March 1996	Pre-plant (dust-mulch fallow)	1.81ab	—	12.5m	—	0.210a	—
March 1997	Pre-plant (spring wheat stubble)	1.25ef	0.89ijk	77.2cd	60.7g	0.012g	0.033g
May 1997	Post-plant (first no-till seeding)	1.66bc	1.59cd	23.4ijk	24.5ijk	0.135de	0.134de
March 1998	Pre-plant (spring wheat stubble)	1.02ghi	1.02ghi	76.1cd	78.9c	0.014g	0.012g
June 1998	Post-plant (second no-till seeding)	1.02ghi	1.02ghi	28.3hi	22.3jk	0.150de	0.198ab
August 1998	Post-harvest (spring wheat stubble)	1.02ghi	0.81jk	93.8a	92.5a	0.005g	0.007g
No-till spring wheat/chemical fallow							
March 1996	Pre-plant (dust-mulch fallow)	1.85ab		20.8kl		0.138de	
March 1997	Spring wheat stubble (6 mo CF)	1.11fgh		73.5cde		0.015g	
March 1998	Spring wheat stubble (18 mo CF)	0.58l		57.2g		0.045g	
June 1998	Post plant (first WS no-till seeding)	1.02ghi		21.3jk		0.228a	
August 1998	Post harvest (spring wheat stubble)			84.5b		0.009g	
March 1997	Post 18 months CF	0.79k		59.8g		0.037g	
May 1997	Post plant (first ES no-till seeding)	1.74abc		15.8lm		0.192abc	
March 1998	Spring wheat stubble (6 mo CF)	1.00ghij		67.3f		0.022g	
June 1998	Spring wheat stubble (9 mo CF)	0.86ijk		58.9g		0.035g	

***† See Table 2**

‡ West side (WS) plots were initially in dust-mulch fallow and east side (ES) plots in winter wheat stubble during fall 1995.

opened furrows and pushed soil onto residue between the furrows (Table 3).

Following the 1996 and 1997 crop harvests, soil residue cover was measured prior to spring planting the following year; therefore, some residue decay would have occurred through the winter. Stott et al. (1990) found less than 10% soil residue cover loss in a no-till system one year following harvest even though residue biomass had declined by as much as 80%. In our study, only 26 weeks elapsed between harvest and spring planting; therefore, late winter soil residue cover measurements would be expected to be a close approximation of soil residue cover immediately following harvest, even though residue biomass may have decreased. Consequently, little decomposition of 1998 crop residues, and accumulation of residue from the previous crop cycles, resulted in soil loss ratio values near zero immediately following the 1998 harvest (Table 3).

Spring wheat/chemical fallow. Residue production in the spring wheat/chemical fallow system ranged from 3660 to 4210 kg ha^{-1} (3268 to 3759 lb ac^{-1}) for the east side and west side respectively. The soil loss ratio remained near zero from harvest through the fallow period as soil residue cover remained above 50% (Table 3). Also, the chemical fallow period was as effective in reducing wind erosion susceptibility as the post-harvest/preplant period in the continuous spring wheat and spring wheat/spring barley rotations. Following the 1998 west side harvest, soil residue cover was 8% to 12% less than soil residue cover measured in the continuous spring wheat and spring wheat/spring barley rotations and illustrated the effect of residue accumulation in the continuous spring crop rotations. Prior to the 1998 harvest, soil residue cover was lower in west side spring wheat/chemical fallow plots compared to continuous spring wheat or spring wheat/spring barley that had residue left from the 1996 and 1997 crop cycles.

In west side plots, soil residue cover declined 16% during an 18-month fallow period, and 8% in east side plots during a 12-month fallow period with no increase in soil loss ratio (Table 3). This rate of soil residue cover loss is consistent with soil residue cover loss reported by Stott et al. (1990). Spring seeding also reduced soil residue cover as the no-till drill openers exposed soil in the furrows, covered residue between the furrows, and increased soil loss ratio. In west side plots, soil loss ratio was highest following the 1998 no-till seeding even though soil residue cover was similar to the dust-mulch fallow initially seeded into in 1996 (Table 3). The increase in soil loss ratio without a decrease in soil residue cover was due to lower random roughness in the no-till system.

Canopy cover. Approximately 75% of wind events occur during spring and fall

(Papendick, 1998); therefore, development of canopy cover is critical in controlling wind erosion on exposed soil. Soil under a growing crop canopy is more protected from wind erosion compared to soil covered by flat residue alone as wind velocity and transport capacity is reduced (Siddoway et al., 1965; Armbrust and Bilbro, 1997). In all no-till spring seeded plots, canopy cover was at least 25% by May and 58% by June resulting in SLR_{cc} values less than 0.14 (Table 4). When canopy cover was combined with random roughness and soil residue cover, the resulting SLR_{comb} erosion potential was not different from zero ($P \leq 0.05$, analysis not shown) except for May 1997 east side spring wheat/chemical fallow and west side continuous spring wheat.

In the west side winter wheat/fallow rotation, winter wheat produced more canopy cover in 30 days than east side winter wheat in 168 days (Table 4.). In 1996, east side plots had to be reseeded after the initial seeding failed to emerge following a soil-crusting rain. The crop was slow to develop and only produced 7% canopy cover in 168 days by March 1997 compared with 44.3% canopy cover in 185 days in 1998 west side plots. The low canopy cover in the east side plots resulted in the highest SLRcc and possibly was a factor in low soil residue cover in the 1998 dust-mulch fallow.

Combining random roughness and soil residue cover effects (SLR in Table 3) with canopy cover effects (SLR_{cc} in Table 4) indicates relative impacts of canopy cover on SLR_{comb} (Table 4). In the winter wheat/fallow rotation, 44% canopy cover was needed for a similar reduction in SLR_{comb} compared with only 27% canopy cover in continuous spring wheat and spring wheat/spring barley rotations (Table 4). This was a result of higher soil residue cover in the no-till rotations compared with winter wheat/fallow. In contrast, the low canopy cover in the 1997 east side winter wheat resulted in the highest SLR_{comb}; therefore, protection from wind erosion was dependent on random roughness and soil residue cover.

Table 4. Effect of crop canopy cover (CC) on wind erosion susceptibility estimated by a canopy cover soil loss ratio (SLR_{cc}) and a combined soil loss ratio (SLR_{comb}) incorporating CC, random roughness (RR), and soil residue cover (SRC).*

Location	Date	DAS†	CC	SLR_{cc}	SLR_{comb}
			(%)	—— (index)†	——
Winter wheat/dust-mulch fallow					
WS	October 1995	30	19.1h	0.193b	0.045b
ES	March 1997	168	7.1i	0.474a	0.086a
WS	March 1998	185	44.3e	0.048e	0.011c
No-till spring wheat/chemical fallow					
ES	May 1997	60	25.6g	0.134c	0.025bc
WS	June 1998	95	59.8cd	0.023f	0.005c
No-till continuous spring wheat					
ES	May 1997	60	27.7g	0.122c	0.011c
ES	June 1998	92	58.3d	0.025f	0.004c
WS	May 1997	60	25.8g	0.134c	0.017c
WS	June 1998	92	64.3a	0.019f	0.003c
No-till spring wheat/spring barley					
ES	May 1997	60	27.0g	0.129c	0.017c
ES	June 1998	95	62.7ab	0.019f	0.004c
WS	May 1997	60	36.3f	0.075d	0.010c
WS	June 1998	92	61.5bc	0.021f	0.003c

***† See Table 2**

† DAS = number of days between crop seeding and canopy cover measurement.

Summary and Conclusion

This research is the first to examine the transitional effect of different no-till spring cropping systems, compared to winter wheat/fallow, on reducing wind erosion susceptibility in the low rainfall region of the Columbia Plateau. This research is important in identifying and developing farming practices that are less susceptible to wind erosion. The research demonstrated that no-till spring cropping is effective in increasing resistance to wind erosion by maintaining soil cover of crop residue and canopy, or both, during dry, windy periods when erosion is traditionally a problem in conventional winter wheat/dust-mulch fallow systems.

The conventional winter wheat/fallow system used on the Columbia Plateau is vulnerable to wind erosion during the dust-mulch fallow period and the degree of vulnerability is dependent on factors including amount of soil residue cover, random roughness, and wind and climate conditions. One of the strongest wind events of the decade occurred September 1999 and resulted in blowing dust and a catastrophic traffic accident on I-84 near Pendleton, Oregon (Hunsberger et al., 1999). The primary source of the fugitive dust was exposed agricultural soil. Where annual precipitation is adequate, no-till spring cropping has the potential to significantly reduce fugitive dust emissions from agricultural soil.

In our reduced tillage winter wheat/fallow treatment, soil residue cover was below 20% during two of the four fallow periods leaving the soil susceptible to erosion, and out of compliance with Alternative Conservation System minimum residue levels established by USDA-NRCS. This illustrates the potential for dust emissions from winter wheat/fallow even during years of above average precipitation and with conservation tillage practices aimed at keeping adequate levels of soil residue cover and random roughness to protect against wind erosion.

In continuous spring wheat and spring wheat/spring barley rotations, soil residue cover approached 100% after the third crop cycle and was likely a result of accumulation of crop residue from the previous crop cycles. The spring wheat/chemical fallow rotation was also effective in keeping residue cover on the surface, even though soil residue cover declined during the 18-month chemical fallow period. The no-till rotations were only slightly susceptible to wind erosion after spring seeding exposed open furrows. However, a growing crop canopy decreased erosion susceptibility by late-spring when dry, windy conditions typically occur.

Random roughness significantly lowered soil loss ratio only during the fallow phase of the winter wheat/fallow rotation when soil residue cover was low. In no-till rotations, random roughness declined during the three-year transition from winter wheat/fallow due to reduced soil disturbance. The soil residue cover and canopy cover were dominant features in the no-till rotations in reducing the erodibility of the soil.

Adopting no-till spring cropping practices in the dryland farming regions of the Columbia Plateau may stabilize soil surface conditions and minimize soil loss to wind erosion; however, further cropping system research is needed to adequately assess the agronomic benefits of no-till spring cropping.

References Cited

Allmaras, R.R., R.E. Burwell, W.E. Larson, and R.F. Holt. 1966. Total porosity and random roughness of the inter-row zone as influenced by tillage. U.S. Department of Agriculture Conservation Research Report No. 7.

Armbrust, D.V. and J.D. Bilbro. 1997. Relating plant canopy coverage characteristics to soil transport capacity by wind. Agronomy Journal 89:157-162.

Bilbro, J.D. and D.W. Fryrear. 1994. Wind erosion losses as related to plant silhouette and soil cover. Agronomy Journal 86:550-553.

D'Amato, G. 1999. Outdoor air pollution in urban areas and allergic respiratory diseases. Monaldi Archives for Chest Disease 54:470-474.

Fryrear, D.W. 1984. Soil ridges-clods and wind erosion. Transactions of the American Society of Agricultural Engineers 27:445-448.

Fryrear, D.W. 1985. Soil cover and wind erosion. Transactions of the American Society of Agricultural Engineers 28:781-784.

Fryrear, D.W., Ali Saleh, J.D. Bilbro, H.M. Schomberg, J.E. Stout, and T.M. Zobeck. 1998. Revised Wind Erosion Equation (RWEQ). Big Spring: Wind Erosion and Water Conservation Research Unit, U.S. Department of Agriculture-Agricultural Research Service, Southern Plains Area Cropping Systems Research Laboratory Technical Bulletin No. 1.

Hinman, H.R. and A.E. Esser. 1999. Enterprise budgets summer fallow/winter wheat rotations and hard red spring wheat annual cropping, Adams County, Washington. Washington State University College of Agriculture and Home Economics, Pullman, Washington. Report No. EB1883.

Hunsberger, B., J. Senior, and S. Carter. 1999. Winds spawn deadly pileups. The Sunday Oregonian September, 26:A01.

Horning, L.B., L.D. Stetler, and K.E. Saxton. 1998. Surface residue and soil roughness for wind erosion protection. Transactions of the American Society of Agricultural Engineers 41:1061-1065.

Hruba, F., E. Fabianova, K. Koppova, and J.J. Vanderberg. 2001. Childhood respiratory symptoms, hospital admissions, and long-term exposure to airborne particulate matter. Journal of Exposure Analysis and Environmental Epidemiology 11:33-40.

Launchbaugh, K., L. McGrew, and F. Young. 2000. Integrated spring cropping systems for the semiarid wheat-fallow region. Washington State University Department of Crop and Soil Sciences, Pullman, Washington. Technical Report No. 00-4.

Littell, R.C., G.A. Miliken, W.W. Stroup, and R.D. Wilfinger. 1996. Statistical Analysis Software systems for mixed models. Statistical Analysis Software (SAS) Institute, Inc., Cary, North Carolina.

Merrill, S.D., A.L. Black, D.W. Fryrear, A. Saleh, T.M. Zobeck, A.D. Halvorson, and D.L Tanaka. 1999. Soil wind erosion hazard of spring wheat-fallow as affected by long-term climate and tillage. Soil Science Society of America Journal 63:1768-1777.

McCool, D.K., K.E. Saxton, and P.W. Mutch. 1996. Rapid method for estimating random roughness. American Society of Agricultural Engineers Paper No. 96-2093.

Papendick, R.I. 1998. Farming with the wind: Best management practices for controlling wind erosion and air quality on Columbia Plateau croplands. Washington State University College Agriculture and Home Economics, Pullman, Washington. Report No. MISC0208.

Papendick, R.I., M.J. Lindstrom, and V.L. Cochran. 1973. Soil mulch effects on seedbed temperature and water during fallow in eastern Washington. Soil Science Society of America Journal 37:307-314.

Saxton, K.E. 1995. Wind erosion and its impact on off-site air quality in the Columbia Plateau-an integrated research plan. Transactions of the American Society of Agricultural Engineers 38:1031-1038.

Saxton, K., D. Chandler, L. Stetler, B. Lamb, C. Claiborn, and B.-H. Lee. 2000. Wind erosion and fugitive dust fluxes on agricultural lands in the Pacific Northwest. Transactions of the American Society of Agricultural Engineers 43:623-630.

Schillinger, W.F. and R.I. Papendick. 1997. Tillage mulch depth effects during fallow on wheat production and wind erosion control factors. Soil Science Society of America Journal 61:871-876.

Scwartz, J. 2001. Is there harvesting in the association of airborne particles with daily deaths and hospital admissions? Epidemiology 12:55-61.

Siddoway, F.H., W.S. Chepil, and D.V. Armbrust. 1965. Effect of kind, amount, and placement of residue on wind erosion control. Transactions of the American Society of Agricultural Engineers 8:327-331.

Sloneker, L.L. and W.C. Moldenhauer. 1977. Measuring the amounts of crop residue remaining after tillage. Journal of Soil and Water Conservation 32(5):231-236.

Sorensen, E. 2000. Dust in the wind: Wastern part of state home to roaming loam. The Seattle Times October, 17:A10.

Stott, D.E., H.F. Stroo, L.F. Elliott, R.I. Papendick, and P.W. Unger. 1990. Wheat residue loss from fields under no-till management. Soil Science Society of America Journal 54:92-90.

Thorne, M. and F. Young. 1998. Integrated spring cropping systems for the semiarid wheat-fallow region. Washington State University Department of Crop and Soil Sciences, Pullman, Washington. Technical Report No. 98-1.

Timblin, C., K. BeruBe, A. Churg, K. Driscoll, T. Gordon, D. Hemenway, E. Walsh, A.B. Cummins, P. Vacek, and B. Mossman. 1998. Ambient particulate matter causes activation of the c-jun kinase/stress-activated protein kinase cascade and DNA synthesis in lung epithelial cells. Cancer Research 58:4543-4547.

U.S. Environmental Protection Agency (USEPA). 1990. Clean air act amendments of 1990: Detailed summary of titles. Title I - Provisions for attainment and maintenance of national ambient air quality standards - ozone, carbon monoxide and PM10 nonattainment provisions. U.S. Environmental Protection Agency, Washington, D.C. Available from www.epa.gov/oar/caa/contents.html.

Zanobetti, A., J. Scwartz, and D.W. Dockery. 2000. Airborne particles are a risk factor for hospital admissions for heart and lung disease. Environmental Health Perspectives 108:1071-1077.